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SIMPLE HIGHSPEED KINEMATOGRAPHY OF NANOSECOND EXPOSURE.

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INTRODUCTION

A nanosecond pulse light source applying a coaxial capacitor of minimum inductance was shown to produce excessive light for single shot photography [1] freezing the motion of fast non luminous objects of minute size [2]. Considerable progress would be obtained if it was possible to fire sequences of such nanosec light pulses adequately timed to a recording camera, thus permitting a time study of the event under investigation. Obviously, however, it appears difficult to produce shotrates and timings which are comparable in time to nanosec exposures i.e. requiring in excess of 10^8 flashes per sec. which would be necessary to study the motion of extremely fast objects.

On the other hand, there are phenomena such as fluid atomization processes which require nanosec exposure in order to freeze because of minute size objects and necessary optical resolution; however, whose absolute velocities are small and will be adequately described by a sequence of exposures applying low shotrate. This combination of short exposure time and low shotrate makes it possible to build a very simple nanosec-exposure multishot-system, since the shotrate may be controlled by the charging-rate of the Lightsource exclusively. The time jitter between single exposures of such free firing source is small. Exposures are taken by means of a drum or other camera, the shutter opening of which may be timed to the phenomenon under observation.

LIGHTSOURCE:

The previously described light source [1, 2] in 1 atmosphere air can be operated with shotrates exceeding 10^4 per sec. because the energy per pulse is small, $\lesssim 10^{-1}$ joules, and because the electrode erosion has been found negligible with current pulses $\lesssim 5 \times 10^{-8}$ sec.

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+ 40 kcycles were produced by F. Früngel by means of pulsed power-supplies

It is important, however, that the electric discharge of the lamp has no substantial current-tail and is prevented from ringing by means of a distributed damping resistor, if necessary. Current-tails may cause heating of electrodes and insulation which can lead to arc phenomena and destruction of the lamp.

In addition it was observed that nanosecond lightpulses in single shot operation, i. e. repetition-rates $\lesssim$10/sec are reproduceable within several percent in light-amplitude and arc-position in such cases when the electrodes are polished and are lined up perfectly [3] within tolerances $\sim$1/100 mm.

Fig. 1 shows that also the untriggered breakdown voltages are reproduceable within a few percent under such conditons. Between shots the signal does not go to zero because of lacking time response of the recorder.

Fig. 1 Breakdown voltages of Nanolite PL-103, untriggered. C = 3.4 nfd. U = 4.2 kV, halfwidth of lightpulse 25 n sec - Varianrecorder - shotrate 1/sec.

This breakdown constancy of the nanosecond discharge on the other hand results in a controlled shotrate when applying a predetermined chargingrate to the lightsource, as is demonstrated in Fig. 2.

Fig. 2 Timing of free firing light source SM-6 C = 0,27 nfd; halfwidth of lightpulse 7 n sec., time base 10 m sec/cm.

Here charging current from the 10 watt, 5 kV power supply is set by means of a resistor in series. The gap breaks at approx. 3.5 kV; The scope is self-triggered at a fixed rate. The observed shotrate of the lightpulse is 770/sec and the time jitter amounts to less than 0,3 msec. This type of source has been operated untriggered with shotrates exceeding 8 kcycles. Total number of shots within one sequence however should be limited to the order of 200 preferably in order to avoid heating.

ARRANGEMENT:

The schematic arrangement of lightsource and camera for the photography of fluid-atomization is shown in Fig. 3.

Fig. 3 Diagram of Arrangement.

The output voltage of the power supply is regulated by the charging resistor and the gap breaks without trigger after the breakdown

voltage is reached. Thus shotrates are controlled by the charging resistor and are predetermined from the calibration curve. The shot-series is started and ended by a timer which can be set between 45 to 500 milliseconds.

The speed of the drum-camera (run by a DC-motor) is observed by a counter. The drum is started before the test and operates in the dark with open shutter since no shutter timing was provided in this particular case. Max. film length is 160 cm as given by the drum circumference. Operation is initiated by the compressing piston in the fluid tank, closing a switch which starts the timing control unit for the flash series. Exit velocities may be changed by a large factor thru piston diameter, speed and nozzle dimensions.

The exit-velocity determines the desirable shotrate; the total time of the shot series is made equal or slightly longer than the time of one revolution of the drum, since the shutter remains open all the time. - Imaging lenssystem, diaphragm and lightsource arrangement are selfexplaining.

RESULTS:

Fig. 4 Water-jet into air, exit-velocity 33 m/sec, nozzle diameter 4 mm

Fig. 4 shows a water jet in 1 atmosphere of air, exit-velocity 33 m/sec from a nozzle, 4 mm diameter. Note the close to equal photographic densities of individual exposures. Occasional bad shots are dark (none in this picture), however do little harm in the analysis of the phenomenon as is discussed in the following. It must be remembered, however, that the width of a single picture is arbitrary more or less and is chosen exclusively from the viewpoint of selecting a suitable image size for the study of the liquid jet. Hence the unequal spacing of individual exposures do represent a relative jitter only, which depends also upon the shotrate. The distance of the diaphragm (see Fig. 4) is 350 mm from the nozzle exit. The actual width of the image is 32 mm and smallest particles observed in this picture are approximately 0.2 mm. The relative motion of such a particle is approximately 0.5% of its actual size during the exposure ($\sim$25 nsec). Hence this particle should still appear sharp on the film even with increased jet velocities exceeding 400 m/sec.
The questions to be asked are - what additional information on the transient phenomenon may be gained by going from a single exposure to a sequence of shots? What shotrate, number of shots and image sizes are desirable? In addition what effect does the time-jitter of the shotrate has upon the information?

Shotrate in Fig. 4 is 6600/sec and the total number of shots 210. Note that individual particles move across the image from top to bottom within approximately 15 frames and there is no appreciable change of the particle shape within this time as may be seen. In other words an individual particle can be seen only for 15 frames with the chosen frequency and exit-velocity. Hence larger shotrate and proportionally more than 15 exposures would not gain more information on individual particles and the apparent time jitter may be disregarded completely for this particular consideration. Larger actual image size in the direction of liquid flow would allow longer observation of the particle on the other hand.

The situation is different, however, in such case where the interest is focused to the statistics of the overall fluid pattern. Here longer shot series may be desired, also larger shotrates, in case of increased nozzle exit-velocities. This means a longer film. Here kinematographic presentation may be considered for the evaluation.

It must be mentioned in this connection that the human eye is extremely sensitive against jerky motion, in other words, the residual time jitter existing in shot series of free firing would be disadvantageous for motion picture observation.

Details of turbulence, boundary layer phenomena, and droplet formation and motion are statistical processes. Although the physical mechanism of liquid jet desintegration can be described [6] by free firing series. During motion picture presentation on other hand the human eye needs at least 3 sec. to get an impression of changes of shape or motion of a particle moving across the image. Thus the particle would move across the picture within 60 frames in case of a projection speed of 20/sec. This value together with the exit velocity determines the shotrate. Finally one should like to see 3 successive particle lifetimes at least. This adds to a total of 180 shots.

FUTURE PLANS

More accurate timing of course may be obtained by application of a pulsed-power supply. Here the shotrate is controlled by the pulserate and the time jitter determined by the risetime of the charging-pulse. This method was used in the past [4] for longer duration light flashes (10^{-7} sec) and required rather expensive electronics so far. Coordination of the camera with the flash may be enforced by a trigger which locks directly to the perforation of the photographic-film [5].

Exact timing of high repetition rate nanosecond lightpulses produced by relatively inexpensive pulsecircuitry will be reported by one of us in the near future.

SUMMARY

Series of nanoflashes with adequate light for photographic observation of nonluminous particles of minute size were obtained in transparent and reflecting light by application of dc-voltage to the light source. Shotrates up to 10 kcycles were produced in such free firing source with a time jitter totalling 0. 3 mm sec. This simple method is adequate for the microscopic evaluation of fluid dissipation processes as it is discussed. Studies of the statistics in overal fluid motion require more exact timing if evaluated by motion picture presentation.

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... taken at the Department of

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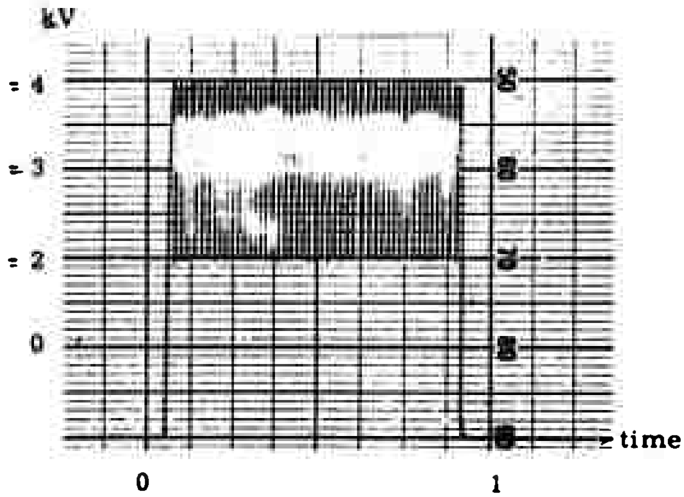


Fig. 1 Breakdown voltages of Nanolite Pl 103 untriggered, 3.4 nfd, 4.2 kV, half-width of lightpulse 20 ns - Varianrecorder - shotrate 1/sec

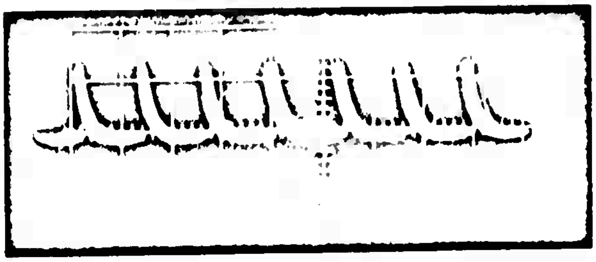
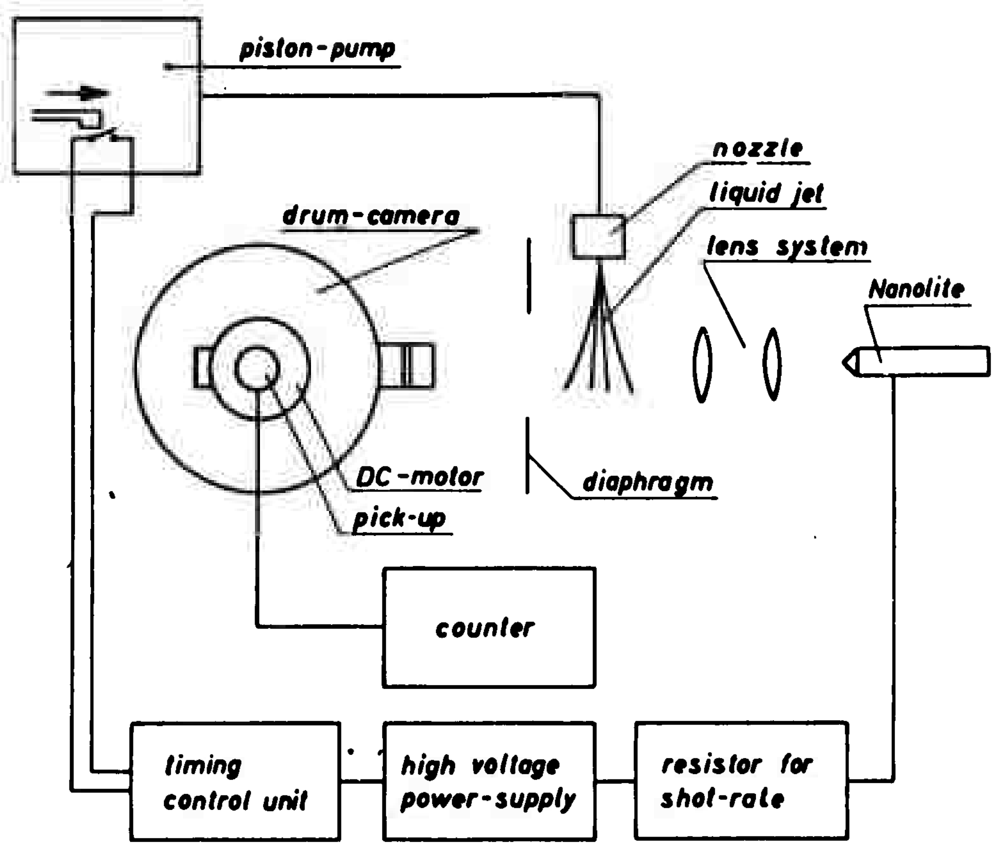


Fig. 2 Timing of free firing light source SM-6, 0. 27 nfd, halfwidth of light-pulse 7 ns, shotrate 770/sec, timebase 1. 0 ms/cm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nozzle
liquid jet
drum-camera
lens system
Nanolite
DC-motor
diaphragm
pick-up
counter
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control unit
high voltage
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resistor for
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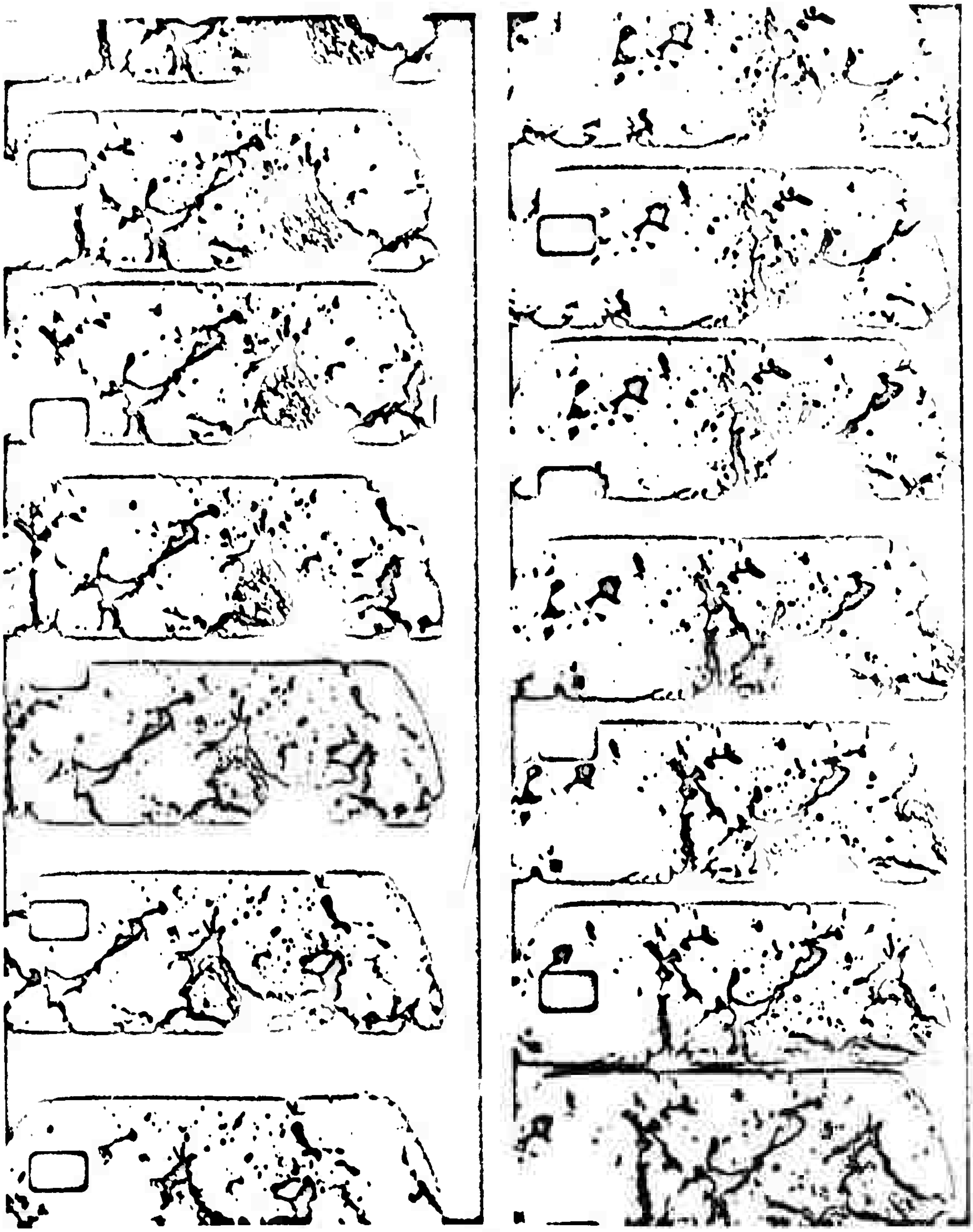

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